# A METHOD OF INTEGRATING A RADIOMETER OUTPUT FOR CLIMATOLOGICAL STUDIES[1]

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[Manuscript received March 20, 1962; revised May 25, 1962]

## ABSTRACT

A method of integrating a radiometer output using operational amplifiers to give 60-min. readout of solar and terrestrial radiation in gm.-cal. cm.$^{-2}$ hr.$^{-1}$ is described. The system also includes a compensation circuit for ambient temperature effect. Results of selected case studies are illustrated by graphs and figures.

## 1. INTRODUCTION

The radiometer integrating circuit is one portion of the Weather Bureau Digital Data System in operation at the Weather Bureau Research Station at the National Reactor Testing Station, Idaho. Considerable thought was given to the method of integration in writing the design specifications and requirements needed in a meteorological digital data system. The two principal types of integrators [1], mechanical (specifically ball and disc integrators) and electronic amplifiers, were considered. Mechanical integrators were considered inferior to electronic integrators with respect to life expectancy and reliability for integrating rapidly varying signals. However, the accuracy of operational amplifiers is known to decrease with the time-period of integration and drift is also a factor [2]. The problem was resolved when performance checks of chopper-stabilized operational amplifiers, Model 3120, commercially available from Donner Scientific Company, indicated high accuracy up to a 1-hour period and little drift for several weeks. These amplifiers employ high forward gain permitting considerable capacitance feedback with precision resistor input.

The overall digital system involves the measurement, integration, and recording on punched paper tape and electric typewriter of the following meteorological quantities: (a) one temperature; (b) two temperature differences; (c) one solar and terrestrial radiation; (d) one dewpoint; (e) two wind speeds and directions in vector form; (f) three vertical winds.

Mr. Richard Fradella, Project Engineer for United Electro-Dynamics Inc., Pasadena, Calif., developed the system according to the U.S. Weather Bureau requirements and specifications. In the following sections the performance of the solar and terrestrial radiation integration and recording system is discussed.

[1] The work described in this paper is supported by an agreement with the Reactor Development Division, U.S. Atomic Energy Commission.

## 2. RADIATION INTEGRATION CIRCUIT

The output of the radiometer is integrated up to 60-min. periods. Ambient temperature effects are compensated by coupling this integrator channel to the ambient temperature signal. The selection of component values was made from the following considerations.

The Beckman and Whitley N188–01 Thermal Radiometer calibration curve (fig. 1) with $F_t$ vs. temperature can be transformed to $1/F_t$ vs. temperature. Between the temperatures −35°F. and 110°F., this transformation yields a straight line relationship with conformity better than 1 percent. Beckman and Whitley stated that the calibration factor varies a small amount from instrument to instrument, but averages about 0.10 gm.-cal. cm.$^{-2}$ min.$^{-1}$ mv.$^{-1}$ DC amplifiers are used as standard equipment in analog computers to perform the mathematical operations of addition, subtraction, integration, and multiplication. These operations are performed by associating precision resistors, capacitors,

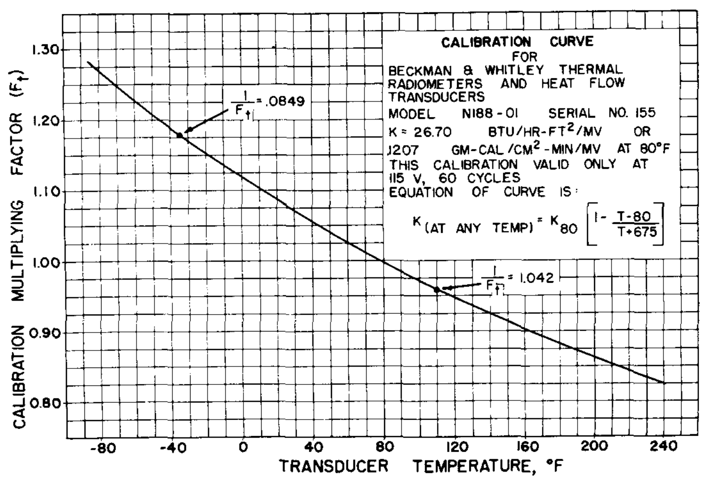


FIGURE 1.—Temperature dependency of radiometer calibration.

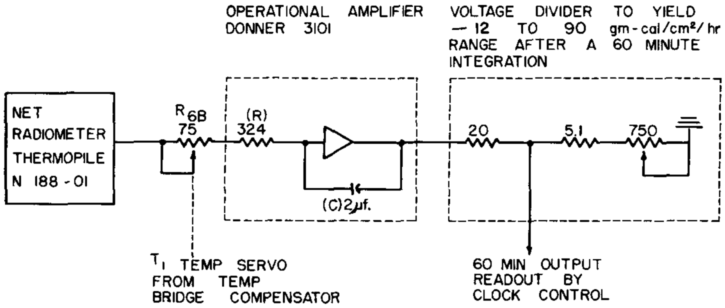


FIGURE 2.—Functional schematic diagram of radiometer integrator. Resistances in the circuits are given in kilo-ohms.

and potentiometers with the basic DC amplifier as described below.

With the selection of a 2-$\mu$f. integrating capacitor, the temperature-compensating resistor $R_{6B}$ (see fig. 2) and the fixed series resistor $R$ should be selected so that the operational amplifier output is less than 100 volts after 60 min. with a 15 mv. radiometer output. We can write

$$E_{R0}=\frac{1}{R(T_1)C}\int_0^t E_{R1}\,dt$$

where

$R(T_1)=R_{6B}(T_1)+R$

$C=2\mu$f. (feedback capacitor)
$E_{R0}=$operational amplifier output voltage
$E_{R1}=$radiometer output voltage
$R=$a fixed series resistor (value to be determined)
$R_{6B}(T_1)=$ambient temperature compensating resistance
$T_1=$ambient temperature (°F.)
$t=$time

If

$$\frac{(.015\text{ v.})(3600\text{ sec.})}{(2\mu\text{f.})R(T_1)}<100\text{v.}$$

then

$$R(T_1)>0.3\text{ megaohm}$$

It can be seen that the temperature effect on $F_t$ can be nullified by making $R(T_t)=\text{const.}/F_t$, and from the graph of $F_t$ vs. temperature, where $T_1$ can vary from $-35°$ to $+110$°F.,

$$0.849[R_{6B}(80°)+R]<R(T_1)<1.042[R_{6B}(80°)+R]$$

Let

$$R=0.849[R_{6B}(80°)+R]$$

then

$$R<R(T_1)<\frac{1.042R}{0.849}=1.227R$$

We can now select $R_{6B}$ (total resistance) to be a 75 kilo-ohm pot with 356° mechanical rotation. Note that from $-35°$ to $+110$°F. the rotation will be 350 mechanical degrees. So,

$$\frac{350}{356}R_{6B}(\text{total})=0.227R=73.72\text{ kilo-ohms}$$

Then

$$R=324\text{ kilo-ohms}$$

With computing elements $C$, $R$, $R_{6B}$ selected to separate ambient temperature $T_1$ from the radiation channel integration output, and with the operational amplifier working in its optimum output voltage range, its output is linearly scaled by a voltage divider to yield the recorded $-12$ to 90 gm.-cal. cm.$^{-2}$ hr.$^{-1}$ range after a 60-min. integration.

## 3. RESULTS

After 8 months of continuous recording of parallel inputs from the radiometer on a Brown Electronik Strip Chart Recorder with 4-sec. pen speed response and the U.S. Weather Bureau Digital Data System, the data were compared.

The digital system gives an integrated readout on the hour; this value is rounded to the nearest langley. The strip chart record is read manually by technicians and integrated over the hour, and temperature and calibration corrections are applied to the record thus giving a langley readout for the same hour. The two different integrating and readout techniques have been compared and graphs drawn. A few of these graphs are shown for different situations.

Figure 3 shows the results on October 4, 1961, a typical day with high scattered clouds and winds southwesterly 6–10 m.p.h. This wind direction is along the ventilation flow over the radiometer. As shown, the comparison is very good; also the actual record of figure 4 is one that is very easy to integrate manually and read.

Figure 5 shows the results on October 6, 1961, a cloudy day with middle and low broken clouds and winds southwesterly 25–35 m.p.h. This graph shows that the operational amplifier type integration is very good. It compares quite favorably to the analog trace as seen in figure 6.

Figure 7 shows the results on August 3, 1961, a day of light northerly winds 3–6 m.p.h. These winds were bucking the normal aspirated flow of the radiometer. The analog trace in figure 8 shows short periods of pen excursions (up scale) due to the bucking effect of the wind. These are low total energy excursions, which seem very much amplified due to great portions of ink above the trace along with the pen width. The digital system shows these excursions as being of short duration.

With strong winds 20–25 m.p.h. bucking the radiometer plate the trace looks entirely different. One doesn't see the low energy excursions that are caused by low wind speeds, but rather a normal trace as shown in figure 9 for November 16, 1961 when winds were northeasterly 20–28 m.p.h. With strong winds the bucking effect is negligible because of aspiration by excessive wind speed.

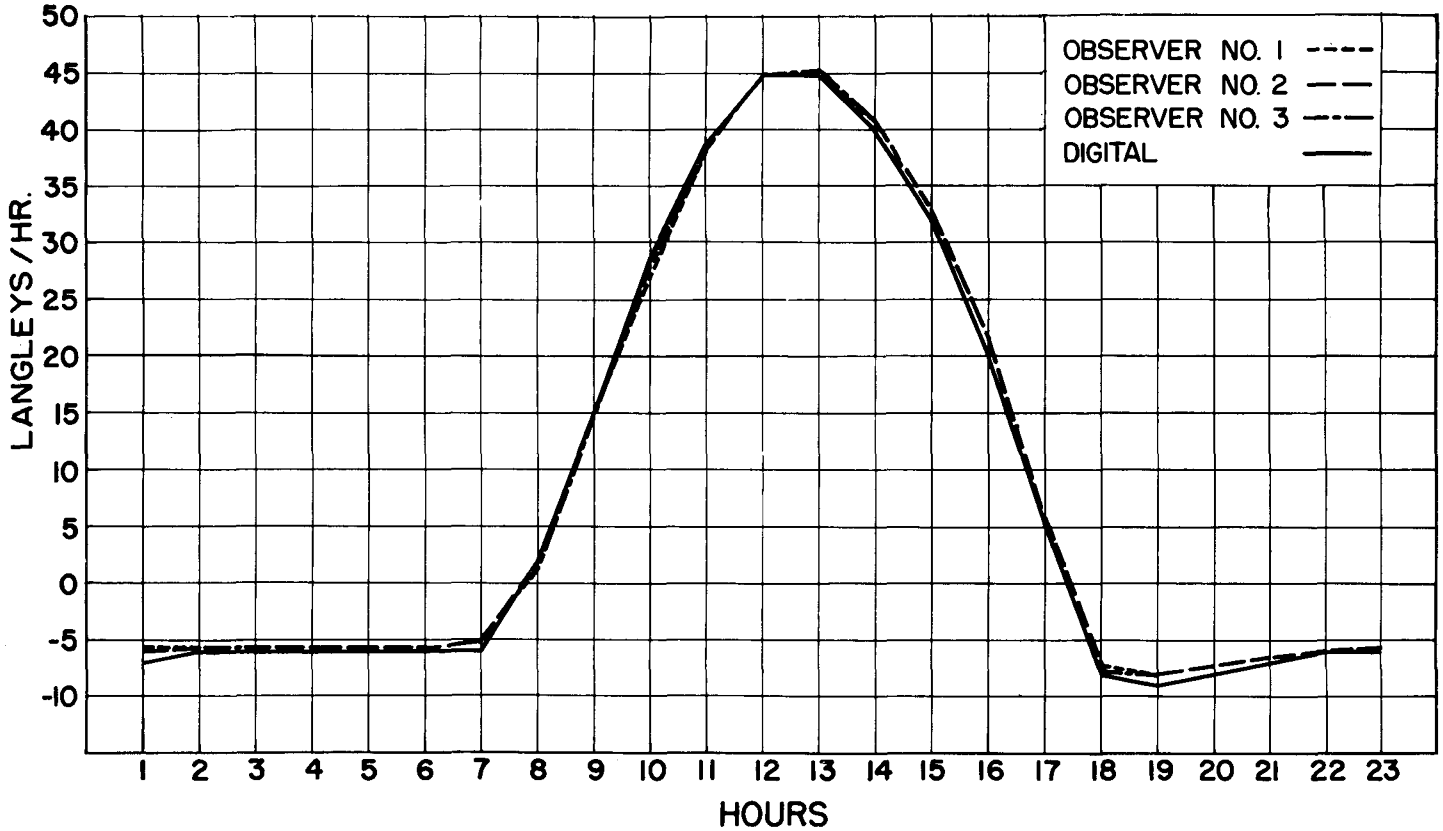


Figure 3.—Digitally integrated hourly radiation versus manual integration of chart record for a day with high scattered clouds, October 4, 1961.

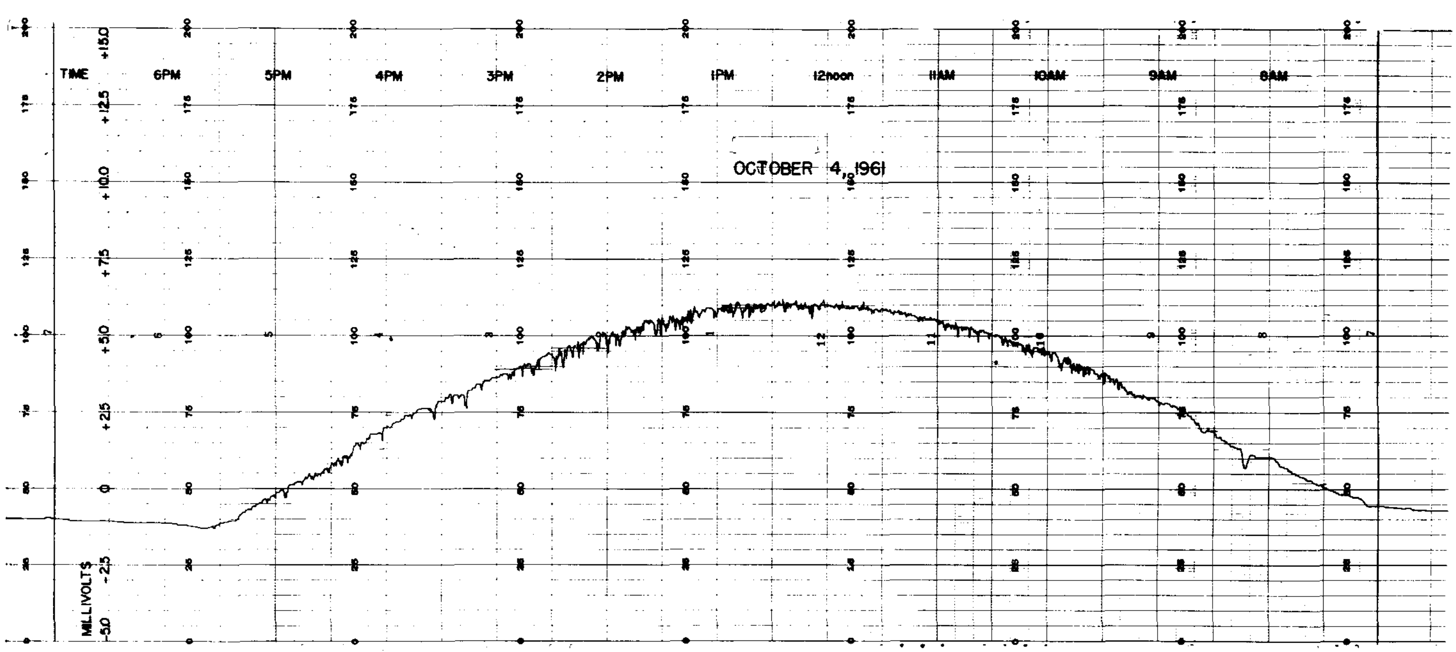


Figure 4.—Analog chart record of radiometer signal for a day with high scattered clouds, October 4, 1961.

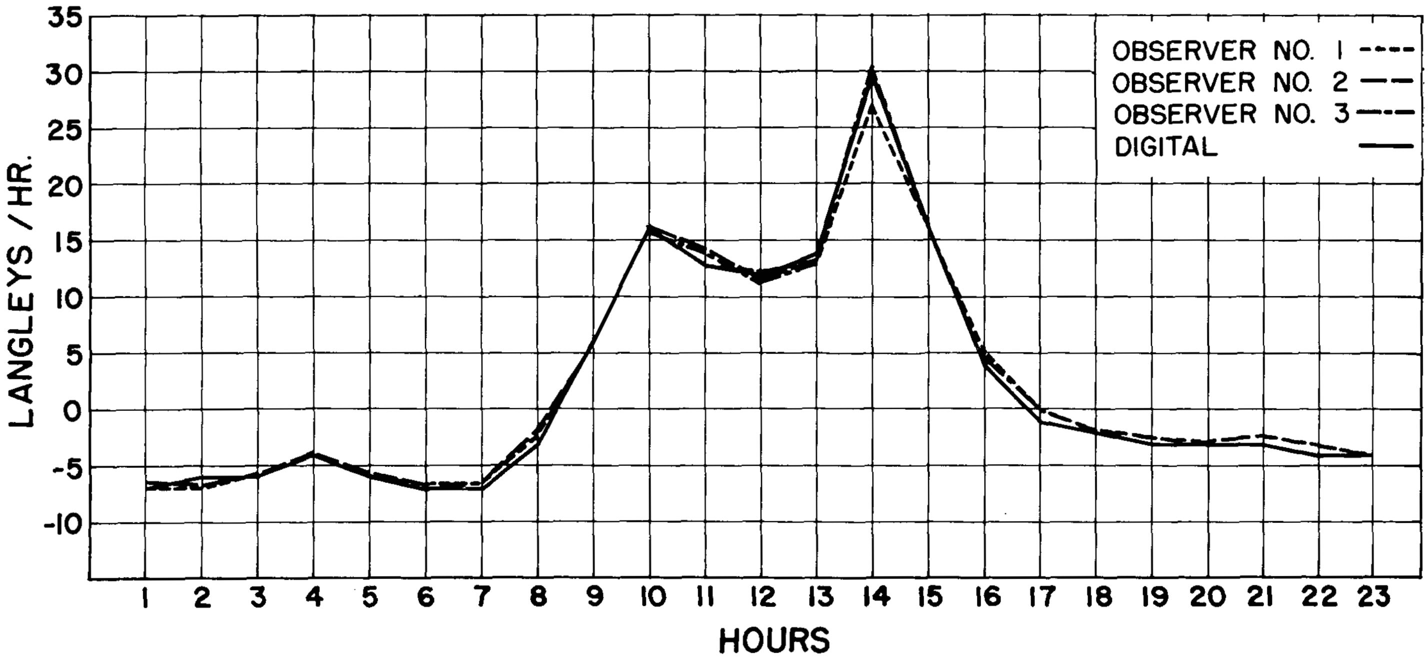


FIGURE 5.—Digitally integrated hourly radiation versus manual integration of chart record for an overcast day, October 6, 1961.

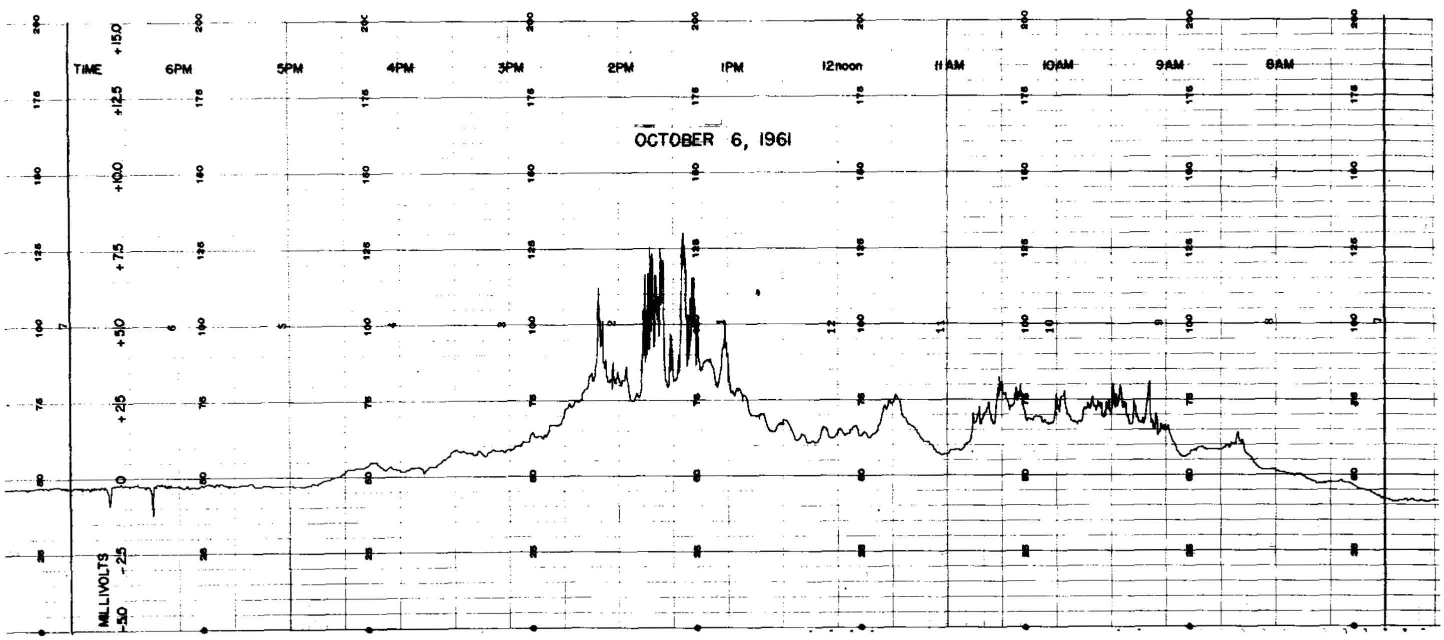


FIGURE 6.—Analog chart record of radiometer signal for a cloudy day, October 6, 1961.

When the system was originally installed it was believed that the integrator would integrate these low total energy signals and thus be in error. Comparisions of many days have shown that the bucking effect due to low northerly wind speeds is negligible in the integration.

Figure 8 is also typical for a low-and-middle-broken-cloudy day in which the chart is somewhat difficult to average by eye. A comparision of the digitally integrated values with those read by four technicians is plotted in figure 7.

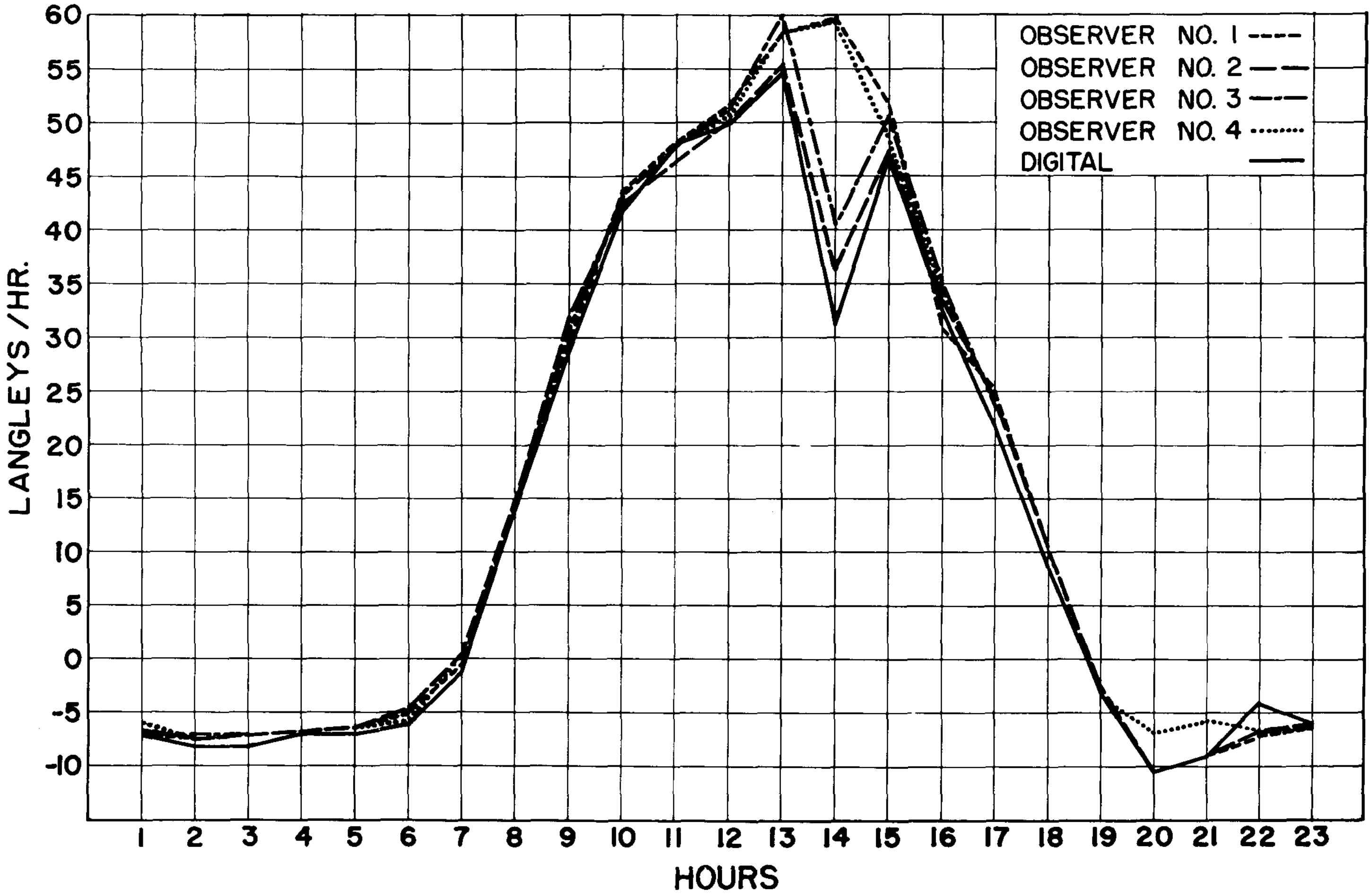


FIGURE 7.—Digitally integrated hourly radiation versus manual integration of chart record for a day with broken cloud cover and light winds bucking the normal radiometer ventilation, August 3, 1961.

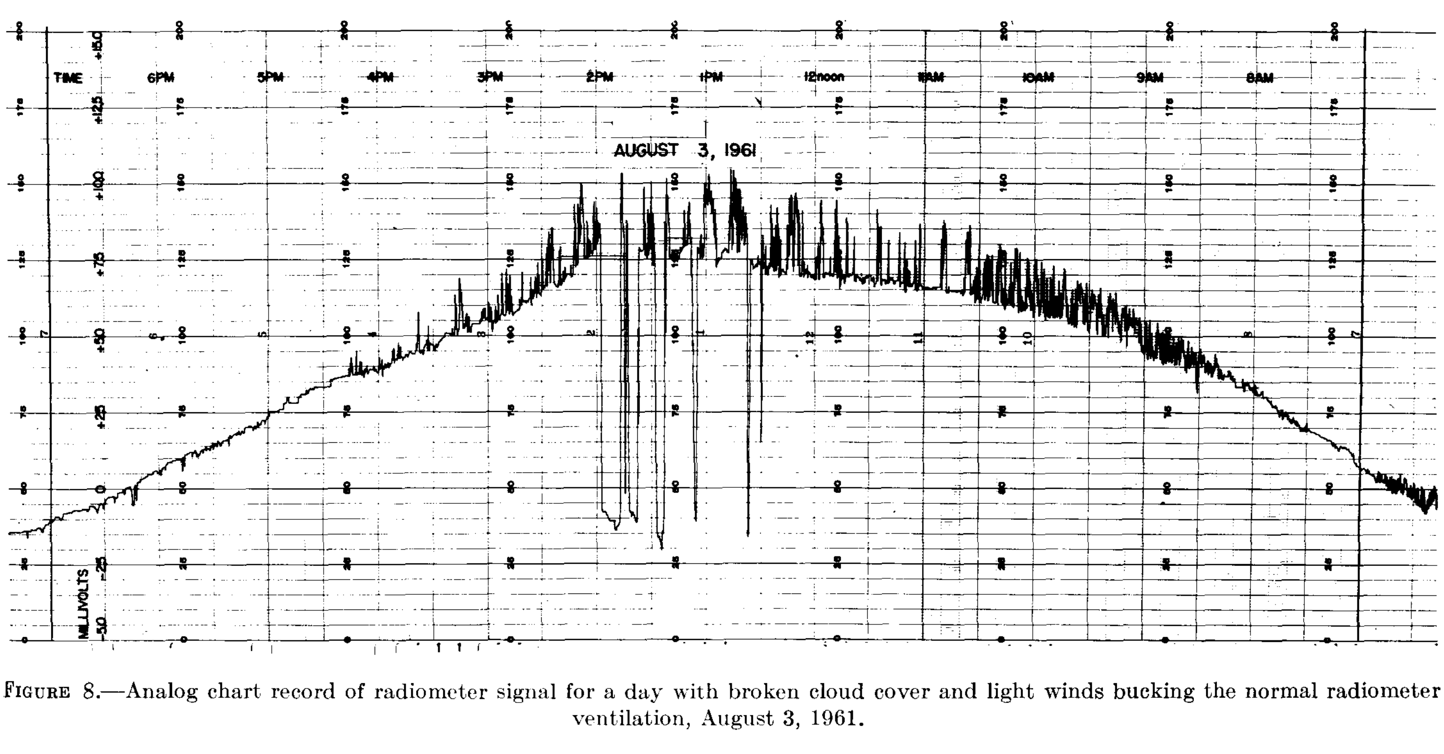


FIGURE 8.—Analog chart record of radiometer signal for a day with broken cloud cover and light winds bucking the normal radiometer ventilation, August 3, 1961.

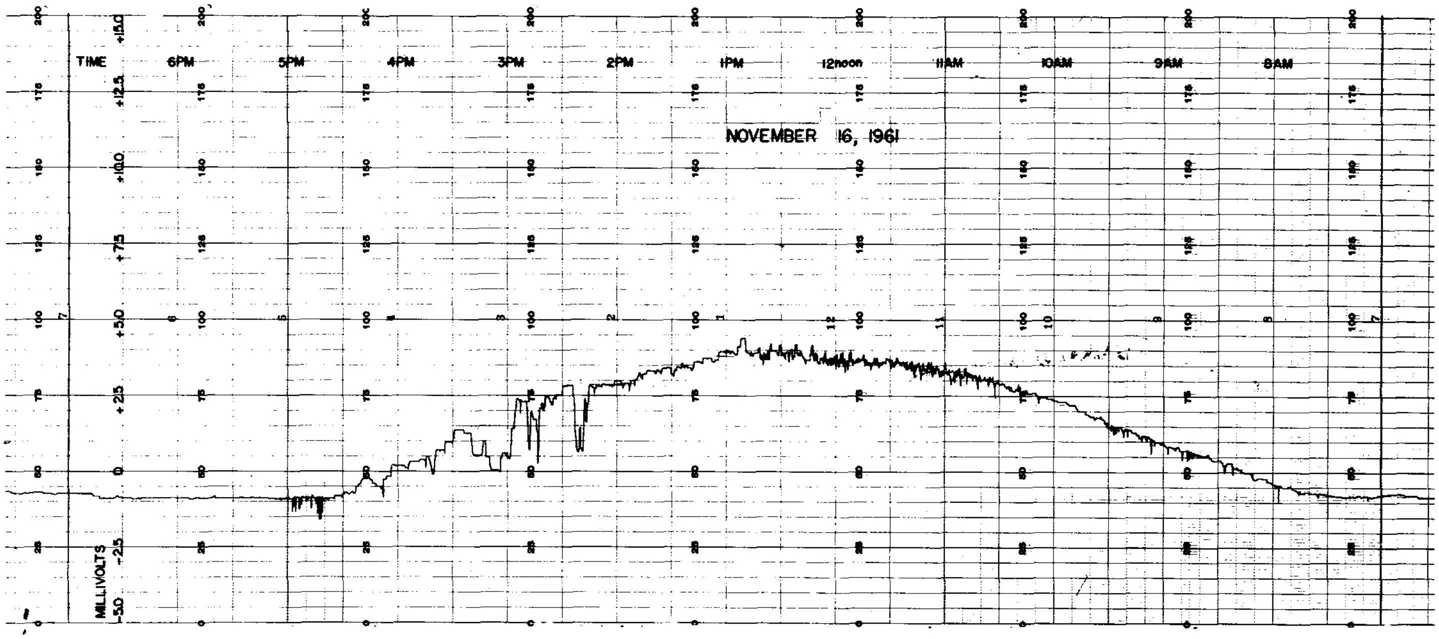


FIGURE 9.—Analog chart record of radiometer signal with strong winds bucking the normal radiometer ventilation, November 16, 1961

The error of the integrating and digitizing equipment is less than 2 percent of full scale for a 60-min. integration period with inputs between 15 percent and 100 percent of full scale.

It is recommended that this technique of integration be incorporated in general Weather Bureau solar and terrestrial radiation systems.

## ACKNOWLEDGMENTS

The work described in this report was supported under contract to the Reactor Development Division, U.S. Atomic Energy Commission. I would like to acknowledge the outstanding contributions made by Richard B. Fradella of the United ElectroDynamics Corporation, Pasadena, Calif., who developed the digital data system and James Speidel who prepared the figures.

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2. P. M. Honnell, "Matrix Programing of Electronic Analog Computors," *A. I. E. E. Communications and Electronics*, No. 38, Paper Nos. 58 to 66, Sept. 1958.